

TITLE OF THE INVENTION
RADIO FRONT END AND APPLICATIONS THEREOF

5 BACKGROUND OF THE INVENTION

TECHNICAL FIELD OF THE INVENTION

This invention relates generally to wireless communication devices and more
10 particularly to radio interfaces of such wireless communication devices.

DESCRIPTION OF RELATED ART

Communication systems are known to support wireless and wire lined
communications between wireless and/or wire lined communication devices. Such
15 communication systems range from national and/or international cellular telephone
systems to the Internet to point-to-point in-home wireless networks. Each type of
communication system is constructed, and hence operates, in accordance with one or
more communication standards. For instance, wireless communication systems may
operate in accordance with one or more standards including, but not limited to, IEEE
20 802.11, Bluetooth, advanced mobile phone services (AMPS), digital AMPS, global
system for mobile communications (GSM), code division multiple access (CDMA), local
multi-point distribution systems (LMDS), multi-channel-multi-point distribution systems
(MMDS), and/or variations thereof.

25 Depending on the type of wireless communication system, a wireless
communication device, such as a cellular telephone, two-way radio, personal digital
assistant (PDA), personal computer (PC), laptop computer, home entertainment
equipment, et cetera communicates directly or indirectly with other wireless
communication devices. For direct communications (also known as point-to-point
30 communications), the participating wireless communication devices tune their receivers
and transmitters to the same channel or channels (e.g., one of the plurality of radio

frequency (RF) carriers of the wireless communication system) and communicate over that channel(s). For indirect wireless communications, each wireless communication device communicates directly with an associated base station (e.g., for cellular services) and/or an associated access point (e.g., for an in-home or in-building wireless network) via an assigned channel. To complete a communication connection between the wireless communication devices, the associated base stations and/or associated access points communicate with each other directly, via a system controller, via the public switch telephone network, via the Internet, and/or via some other wide area network.

For each wireless communication device to participate in wireless communications, it includes a built-in radio transceiver (i.e., receiver and transmitter) or is coupled to an associated radio transceiver (e.g., a station for in-home and/or in-building wireless communication networks, RF modem, etc.). As is known, the transmitter includes a data modulation stage, one or more intermediate frequency stages, and a power amplifier. The data modulation stage converts raw data into baseband signals in accordance with a particular wireless communication standard. The one or more intermediate frequency stages mix the baseband signals with one or more local oscillations to produce RF signals. The power amplifier amplifies the RF signals prior to transmission via an antenna.

As is also known, the receiver is coupled to the antenna and includes a low noise amplifier, one or more intermediate frequency stages, a filtering stage, and a data recovery stage. The low noise amplifier receives inbound RF signals via the antenna and amplifies them. The one or more intermediate frequency stages mix the amplified RF signals with one or more local oscillations to convert the amplified RF signal into baseband signals or intermediate frequency (IF) signals. The filtering stage filters the baseband signals or the IF signals to attenuate unwanted out of band signals to produce filtered signals. The data recovery stage recovers raw data from the filtered signals in accordance with the particular wireless communication standard.

In many wireless applications, a radio transceiver includes one antenna that is shared by the receiver section and the transmitter section. The sharing of the antenna may be achieved by a transmit/receive switch or a transformer balun. In recent advances in the wireless communication art, a transformer balun has been implemented on-chip with the receiver section and the transmitter section. In such an implementation, a single-ended winding of the transformer balun is operably coupled to the antenna, a first differential winding of the transformer balun is operably coupled to the receiver section, and another differential winding of the transformer balun is operably coupled to the transmitter section.

While the benefits of using an on-chip balun are many, there are some issues of concern, which include impedance matching of the loads on the single-ended winding and on the differential winding, efficient energy transfer from the transmitter section to the antenna via the transformer balun, and complexity of implementation. Such issues arise, at least in part, due to the loading of the transformer balun varies depending on whether the transceiver is in a transmit mode or in a receive mode. For example, the input impedance of the low noise amplifier, which is a load on the differential winding, varies by a factor of two or more depending on whether the low noise amplifier is active or inactive. Further, the output impedance of the power amplifier, which is a load on the differential winding, varies depending on whether the power amplifier is active or inactive.

Therefore, a need exists for a radio front end that provides for efficient energy transfer from the transmitter section to the antenna, provides enhanced impedance matching, and reduces the complexity of implementation.

BRIEF SUMMARY OF THE INVENTION

The radio front end of the present invention substantially meets these needs and others. In one embodiment, a radio front end includes a transformer and an adjustable load. The transformer includes a first winding and a second winding, wherein the first winding is operably coupled to an antenna and the second winding coupled to at least one

of a power amplifier and a low noise amplifier. The adjustable load is operably coupled to the second winding, wherein the adjustable load provides a first impedance based on a first impedance selection signal when the radio front end is in a transmit mode and provides a second impedance based on a second impedance selection signal when the
5 radio front end is in a receive module such that impedance at the first winding is substantially similar in the transmit mode and in the receive mode.

In another embodiment, a radio front end includes a transformer and an adjustable load. The transformer includes a first winding and a second winding, wherein the first
10 winding is operably coupled to an antenna and the second winding coupled to at least one of a power amplifier and a low noise amplifier. The adjustable load is operably coupled to the first winding, wherein the adjustable load provides a first impedance based on a first impedance selection signal when the radio front end is in a transmit mode and provides a second impedance based on a second impedance selection signal when the
15 radio front end is in a receive module such that impedance at the first winding is substantially similar in the transmit mode and in the receive mode.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

Figure 1 is a schematic block diagram of a wireless communication system in
20 accordance with the present invention;

Figure 2 is a schematic block diagram of a wireless communication device in accordance with the present invention;

25 Figure 3 is a schematic block diagram of a radio front-end in accordance with the present invention;

Figure 4 is a schematic block diagram of another embodiment of a radio front-end in accordance with the present invention;

30

Figure 5 is a schematic block diagram of yet another embodiment of a radio front-end in accordance with the present invention;

Figure 6 is a schematic block diagram of a further embodiment of a radio front-
5 end in accordance with the present invention;

Figure 7 is a schematic block diagram of a still further embodiment of a radio front-end in accordance with the present invention;

10 Figure 8 is a schematic block diagram of yet another embodiment of a radio front-end in accordance with the present invention; and

Figure 9 is a schematic block diagram of a still further embodiment of a radio front-end in accordance with the present invention.

15

DETAILED DESCRIPTION OF THE INVENTION

Figure 1 is a schematic block diagram illustrating a communication system 10 that includes a plurality of base stations and/or access points 12-16, a plurality of wireless communication devices 18-32 and a network hardware component 34. The wireless
20 communication devices 18-32 may be laptop host computers 18 and 26, personal digital assistant hosts 20 and 30, personal computer hosts 24 and 32 and/or cellular telephone hosts 22 and 28. The details of the wireless communication devices will be described in greater detail with reference to Figure 2.

25 The base stations or access points 12-16 are operably coupled to the network hardware 34 via local area network connections 36, 38 and 40. The network hardware 34, which may be a router, switch, bridge, modem, system controller, et cetera provides a wide area network connection 42 for the communication system 10. Each of the base stations or access points 12-16 has an associated antenna or antenna array to
30 communicate with the wireless communication devices in its area. Typically, the wireless communication devices register with a particular base station or access point 12-

14 to receive services from the communication system 10. For direct connections (i.e., point-to-point communications), wireless communication devices communicate directly via an allocated channel.

5 Typically, base stations are used for cellular telephone systems and like-type systems, while access points are used for in-home or in-building wireless networks. Regardless of the particular type of communication system, each wireless communication device includes a built-in radio and/or is coupled to a radio. The radio includes a highly linear amplifier and/or programmable multi-stage amplifier as disclosed herein to
10 enhance performance, reduce costs, reduce size, and/or enhance broadband applications.

Figure 2 is a schematic block diagram illustrating a wireless communication device that includes the host device 18-32 and an associated radio 60. For cellular telephone hosts, the radio 60 is a built-in component. For personal digital assistants
15 hosts, laptop hosts, and/or personal computer hosts, the radio 60 may be built-in or an externally coupled component.

As illustrated, the host device 18-32 includes a processing module 50, memory 52, radio interface 54, input interface 58 and output interface 56. The processing module
20 50 and memory 52 execute the corresponding instructions that are typically done by the host device. For example, for a cellular telephone host device, the processing module 50 performs the corresponding communication functions in accordance with a particular cellular telephone standard.

25 The radio interface 54 allows data to be received from and sent to the radio 60. For data received from the radio 60 (e.g., inbound data), the radio interface 54 provides the data to the processing module 50 for further processing and/or routing to the output interface 56. The output interface 56 provides connectivity to an output display device such as a display, monitor, speakers, et cetera such that the received data may be
30 displayed. The radio interface 54 also provides data from the processing module 50 to the radio 60. The processing module 50 may receive the outbound data from an input

device such as a keyboard, keypad, microphone, et cetera via the input interface 58 or generate the data itself. For data received via the input interface 58, the processing module 50 may perform a corresponding host function on the data and/or route it to the radio 60 via the radio interface 54.

5

Radio 60 includes a host interface 62, digital receiver processing module 64, an analog-to-digital converter 66, a filtering/gain module 68, an IF mixing down conversion stage 70, a low noise amplifier 72, a radio front end 85, a local oscillation module 74, memory 75, a digital transmitter processing module 76, a digital-to-analog converter 78,
10 a filtering/gain module 80, an IF mixing up conversion stage 82, a power amplifier 84, and an antenna 86. The antenna 86 is shared by the transmit and receive paths via the radio front end 85, which will be described in greater detail with reference to Figures 3 - 9.

15 The digital receiver processing module 64 and the digital transmitter processing module 76, in combination with operational instructions stored in memory 75, execute digital receiver functions and digital transmitter functions, respectively. The digital receiver functions include, but are not limited to, digital intermediate frequency to baseband conversion, demodulation, constellation demapping, decoding, and/or
20 descrambling. The digital transmitter functions include, but are not limited to, scrambling, encoding, constellation mapping, modulation, and/or digital baseband to IF conversion. The digital receiver and transmitter processing modules 64 and 76 may be implemented using a shared processing device, individual processing devices, or a plurality of processing devices. Such a processing device may be a microprocessor,
25 micro-controller, digital signal processor, microcomputer, central processing unit, field programmable gate array, programmable logic device, state machine, logic circuitry, analog circuitry, digital circuitry, and/or any device that manipulates signals (analog and/or digital) based on operational instructions. The memory 75 may be a single memory device or a plurality of memory devices. Such a memory device may be a read-
30 only memory, random access memory, volatile memory, non-volatile memory, static memory, dynamic memory, flash memory, and/or any device that stores digital

information. Note that when the processing module 64 and/or 76 implements one or more of its functions via a state machine, analog circuitry, digital circuitry, and/or logic circuitry, the memory storing the corresponding operational instructions is embedded with the circuitry comprising the state machine, analog circuitry, digital circuitry, and/or logic circuitry.

In operation, the radio 60 receives outbound data 94 from the host device via the host interface 62. The host interface 62 routes the outbound data 94 to the digital transmitter processing module 76, which processes the outbound data 94 in accordance with a particular wireless communication standard (e.g., IEEE 802.11 Bluetooth, et cetera) to produce digital transmission formatted data 96. The digital transmission formatted data 96 will be a digital base-band signal or a digital low IF signal, where the low IF typically will be in the frequency range of one hundred kilohertz to a few megahertz.

The digital-to-analog converter 78 converts the digital transmission formatted data 96 from the digital domain to the analog domain. The filtering/gain module 80 filters and/or adjusts the gain of the analog signal prior to providing it to the IF mixing stage 82. The IF mixing stage 82 converts the analog baseband or low IF signal into an RF signal based on a transmitter local oscillation 83 provided by local oscillation module 74. The power amplifier 84 amplifies the RF signal to produce outbound RF signal 98, which is provide to the antenna 86 via the radio front end 85, where the antenna 86 transmits the outbound RF signal 98 to a targeted device such as a base station, an access point and/or another wireless communication device.

The radio 60 also receives an inbound RF signal 88 via the antenna 86, which was transmitted by a base station, an access point, or another wireless communication device. The antenna 86 provides the inbound RF signal 88 to the low noise amplifier 72 via the radio front end 85. The low noise amplifier 72 amplifies the signal 88 to produce an amplified inbound RF signal. The low noise amplifier 72 provides the amplified inbound RF signal to the IF mixing module 70, which directly converts the amplified inbound RF

signal into an inbound low IF signal or baseband signal based on a receiver local oscillation 81 provided by local oscillation module 74. The down conversion module 70 provides the inbound low IF signal or baseband signal to the filtering/gain module 68. The filtering/gain module 68 filters and/or gains the inbound low IF signal or the inbound baseband signal to produce a filtered inbound signal.

The analog-to-digital converter 66 converts the filtered inbound signal from the analog domain to the digital domain to produce digital reception formatted data 90. The digital receiver processing module 64 decodes, descrambles, demaps, and/or demodulates the digital reception formatted data 90 to recapture inbound data 92 in accordance with the particular wireless communication standard being implemented by radio 60. The host interface 62 provides the recaptured inbound data 92 to the host device 18-32 via the radio interface 54.

As one of average skill in the art will appreciate, the wireless communication device of figure 2 may be implemented using one or more integrated circuits. For example, the host device may be implemented on one integrated circuit, the digital receiver processing module 64, the digital transmitter processing module 76 and memory 75 may be implemented on a second integrated circuit, and the remaining components of the radio 60, less the antenna 86, may be implemented on a third integrated circuit. As an alternate example, the radio 60 may be implemented on a single integrated circuit. As yet another example, the processing module 50 of the host device and the digital receiver and transmitter processing modules 64 and 76 may be a common processing device implemented on a single integrated circuit. Further, the memory 52 and memory 75 may be implemented on a single integrated circuit and/or on the same integrated circuit as the common processing modules of processing module 50 and the digital receiver and transmitter processing module 64 and 76.

Figure 3 is a schematic block diagram of an embodiment of a radio front-end 85 that includes a transformer 100 and an adjustable load 106. The transformer 100 includes a 1st winding 102 and a 2nd winding 104. The 1st winding may be a single-ended winding

operably coupled to a circuit ground and to an antenna 86. The 2nd winding 104 may be a differential winding having a center tap coupled to circuit ground and the other nodes coupled to the adjustable load 106. The adjustable load 106 is adjusted based on an impedance selection signal 108 and is coupled to the low noise amplifier 72 and power amplifier 84. The adjustable load provides a 1st impedance based on the impedance selection signal 108 when the radio front-end is in a transmit mode (i.e., the power amplifier 84 is enabled and low noise amplifier 72 is disabled) and provides a 2nd impedance based on the impedance selection signal 108 when the radio front-end is in a receive mode (i.e., the power amplifier 84 is off and the low noise amplifier 72 is on) such that the impedance on the 1st winding is substantially similar in the transmit mode and in the receive mode of the radio.

In operation, the loading on the 2nd winding 104 varies depending on whether the power amplifier 84 is enabled or the low noise amplifier 72 is enabled. During a calibration function of the wireless communication device, the particular loading during the transmit and receive modes may be determined. Based on this determination, the impedance selection signal 108 may be generated to provide the desired loading of adjustable load 106 such that it provides a 1st load during transmit mode and a 2nd impedance during receive mode such that the load on the 2nd winding 104 remains substantially constant whether the radio is in a transmit mode or receive mode.

Figure 4 is a schematic block diagram of another embodiment of the radio front-end 85. In this embodiment, the radio front-end 85 includes the transformer 100 and an adjustable load 110. In this embodiment, the 2nd winding 104 of transformer 100 is directly coupled to the low noise amplifier 72 and power amplifier 84. The 1st winding 102 is operably coupled to the adjustable load 110, which is adjusted based on the impedance selection signal 108.

To compensate for the different loading effects on the secondary winding when the low noise amplifier is enabled or the power amplifier is enabled, the adjustable load 110 is adjusted such that the input impedance of the transformer 100 appears

substantially constant regardless of whether the radio is in a transmit mode or receive mode. As one of average skill in the art will appreciate, if the antenna 86 has an impedance of approximately 50 OHMS in the frequency range of interest, the input impedance to the radio should substantially equal 50 OHMS. By including the adjustable
5 load 110, and/or adjustable load 106, the input impedance to the radio can remain substantially constant regardless of whether the radio is in a transmit mode or receive mode.

Figure 5 is a schematic block diagram of yet another embodiment of the radio
10 front-end 85. In this embodiment, the transformer 100 includes the 1st and 2nd windings, where the 1st winding may be coupled to the adjustable load 110 and the 2nd winding may be coupled to the adjustable load 106. As one of average skill in the art will appreciate, the radio front-end 85 of Figure 5 may include one or both of the adjustable loads 106 and/or 110.

15 In this embodiment, the adjustable load 106 includes a variable capacitor C1 that is coupled across the 2nd winding. The adjustable capacitor C1 may be implemented as a capacitor bank, a varactor or a combination thereof. The control of the variable capacitance C1 is done by the impedance selection signal 108. Similarly, the adjustable
20 load 110 may be implemented using a variable capacitance C2 that is controlled via the impedance selection signal 108. The variable capacitance C2 may be implemented by a capacitor bank and/or a varactor.

Figure 6 illustrates yet another embodiment of a radio front-end 85 that includes
25 transformer 100 and adjustable load 106 and/or adjustable load 110. In this embodiment, the adjustable load 110 includes the variable capacitor C2.

The adjustable load 106 includes variable capacitors C3 and C4 each of which is coupled to a node of the 2nd winding and to circuit ground. Each of capacitors C3 and C4
30 may be a capacitor bank and/or varactor that is controlled via the impedance selection signal 108.

Figure 7 is a schematic block diagram of a further embodiment of the radio front-end 85 that includes transformer 100 and adjustable load 106 and/or adjustable load 110. In this embodiment, the adjustable loads 106 and 110 include variable inductors L_1 , L_2 and L_3 coupled in series with the corresponding windings. The adjustable inductors L_1 - L_3 may be implemented using an inductor bank that is controlled by the impedance selection signal. Accordingly, by adjusting the inductance added in series with the windings of transformer 100, the corresponding input impedance of the radio may be controlled such that it remains substantially constant whether the radio is in a transmit mode or receive mode.

Figure 8 is a schematic block diagram of a still further embodiment of the radio front-end 85 that includes transformer 100 and adjustable loads 106 and/or adjustable load 110. In this embodiment, the adjustable loads 106 and 110 include variable shunt inductors L_4 - L_6 that are controlled via the input selection signal 108. The inductors L_4 - L_6 may be an inductor bank.

Figure 9 illustrates yet another embodiment of a radio front-end 85. In this embodiment, transformer 101 includes a 1st winding 103 and a 2nd winding 105. The 1st winding 103 is coupled to the adjustable load 110, which may be implemented in any one of the previous Figures 5-8.

The 2nd winding 105 includes a center tap operably coupled to circuit ground, a 1st pair of windings and a 2nd pair of windings. The 1st pair of windings has its nodes coupled to the adjustable load circuit 114 and adjustable load circuit 116, which are in turn, coupled to the low noise amplifier 72. The 2nd pair of windings has their nodes coupled to adjustable load circuits 112 and 118 which in turn are coupled to power amplifier 84. In this embodiment, the adjustable load circuits 112-118 may be implemented as previously described with reference to Figures 5-8.

As one of average skill in the art will appreciate, the values of the capacitors and/or inductors used in the adjustable loads and/or load circuits depends on the load variations induced by the low noise amplifier 72 and power amplifier 84, the inductance of transformer 101 and the operating frequency of the receive and/or transmitted RF signals. For instance, the capacitance values may range from a few hundredths of pico-farads to tens of pico-farads where the inductance may range from a few hundredths of nano-farads to a few nano-farads.

As one of average skill in the art will appreciate, the term “substantially” or “approximately”, as may be used herein, provides an industry-accepted tolerance to its corresponding term. Such an industry-accepted tolerance ranges from less than one percent to twenty percent and corresponds to, but is not limited to, component values, integrated circuit process variations, temperature variations, rise and fall times, and/or thermal noise. As one of average skill in the art will further appreciate, the term “operably coupled”, as may be used herein, includes direct coupling and indirect coupling via another component, element, circuit, or module where, for indirect coupling, the intervening component, element, circuit, or module does not modify the information of a signal but may adjust its current level, voltage level, and/or power level. As one of average skill in the art will also appreciate, inferred coupling (i.e., where one element is coupled to another element by inference) includes direct and indirect coupling between two elements in the same manner as “operably coupled”. As one of average skill in the art will further appreciate, the term “compares favorably”, as may be used herein, indicates that a comparison between two or more elements, items, signals, etc., provides a desired relationship. For example, when the desired relationship is that signal 1 has a greater magnitude than signal 2, a favorable comparison may be achieved when the magnitude of signal 1 is greater than that of signal 2 or when the magnitude of signal 2 is less than that of signal 1.

The preceding discussion has presented a radio front-end that includes a substantially constant input impedance regardless of whether a radio is in a transmit mode or receive mode. As one of average skill in the art will appreciate, other

embodiments may be derived from the teaching of the present invention without deviating from the scope of the claims.